Stereo matching technique using Belief Propagation

Annual Progress Seminar

Submitted in partial fulfillment of the requirement of

University of Mumbai

For the Degree of

Philosophy of Doctor
(Electronics Engineering)

by

Chitra Suresh

Under the guidance of

Dr.Kushal R Tuckley

Department of Electronics Engineering
Ramrao Adik Institute of Technology,
Sector 7, Nerul , Navi Mumbai
(Affiliated to University of Mumbai)
Oct 2015

Ramrao Adik Education Society's
Ramrao Adik Institute of Technology
(Affiliated to the University of Mumbai)
Dr. D. Y. Patil Vidyanagar,Sector 7, Nerul, Navi Mumbai 400 706.

Certificate

This is to certify that, the Annual Progress Seminar entitled

"Analysis of Stereo matching Algorithm using Belief Propagation"

is a bonafide work done by

Chitra Suresh

and is submitted in the partial fulfillment of the requirement for the degree of

Doctor of Philosophy
in
Electronics Engineering
to the
University of Mumbai.

Examiner	Supervisor

Project Coordinator	Head of Department	Principal

Acknowledgments

With great pleasure, I avail this opportunity to express my deep sense of gratitude to my guide **Dr.Kushal Tuckley** for his spirited guidance and inspiration. I have deep sense of admiration for their innate goodness and inexhaustible enthusiasm. It helped me to work in right direction to attain desired objective.

I am also thankful to our HOD and PhD Coordinator, **Dr. Mukesh D. Patil** who devoted their valuable time and helped me in all possible ways towards successful completion of this work. I thank all those who have contributed directly or indirectly to this work.

I am thankful to our Principal **Dr. Ramesh Vasappanavara** for his support and encouragement. I cannot end without thanking my lovely family

I would also like to express my deepest thanks to all my friends and my colleagues, who provided a perfect environment for my studies.

Last but not least, I would like to express my heartily gratitude to my family for their unconditional support and love.

Abstract

Stereo vision is an imaging technique that can provide full field of view 3D measurements in an unstructured and dynamic environment.The key problem to solve stereo vision are to identify which pixel in multiple images match the same world feature .This problem is known as stereo matching or stereo correspondence. Stereo Matching is for a given two or more images of the same scene or object, compute a representation of its shape. Stereo Matching is process of finding disparity or depth information.
There are many algorithms for stereo matching have been proposed, the computation of disparity still remains challenging in texture less regions, depth discontinuities and occluded areas.The stereo matching problems can formulate in terms of Markov Random Field as minimum energy function, to find energy minimization function is NP-hard. This means a general solution to this problem will take an unthinkably long time to reach a solution.
Belief propagation algorithm is an approach which find the approximate solution for minimum energy functions used for stereo matching. Belief propagation algorithm considers both vertical and horizontal consistency is most robust method in the presence of texture less regions and occlusion.
Keywords:Stereo matching ,Markov Random Field and Belief Propagation

List of Figures

Contents

Chapter 1

Introduction

Stereo vision is an imaging technique that can provide full field of view 3D measurements in an unstructured and dynamic environment. The basic of stereo vision are similar to 3D perception in a human vision and is based on triangulation of rays from multiple view-points. Each pixel in a digital camera collects the light that reaches the camera along a 3D ray. If feature in the world can be identified as a pixel location in an image then this feature lies on the 3D ray associated with that pixel. If multiple cameras are used multiple rays are obtained. The intersection of these rays is the 3D location of the feature.
The key problem to solve stereo vision are to identify which pixel in multiple images match the same world feature .This problem is known as stereo matching or stereo correspondence. Stereo Matching is for a given two or more images of the same scene or object, compute a representation of its shape. Stereo Matching is process of finding disparity or depth information.
The tracing of corresponding phenomena i.e. stereo matching is necessary key funtionality in many applications like image sequence analysis in entertainment, information transfer and automated systems. Stereo matching is highly important in fields such as robotics to extract information about the relative position of 3D objects in the vicinity of autonomous systems. Other applications for robotics include object recognition, where depth information allows for the system to separate occluding image components, such as one chair in front of another, which the robot may not be able to distinguish as a separate object by any other criteria.
Scientific applications for digital stereo vision include the extraction of information from aerial surveys, for calculation of contour maps or even geometry extraction for 3D building mapping, or calculation of 3D heliographic information such as obtained by the remote sensing projects of the ISRO .

There are many algorithms for stereo matching have been proposed, the computation of disparity still remains challenging in texture less regions, depth discontinuities and occluded areas. The stereo algorithms can be roughly categorized into three classes.
The first class is the area-based algorithms. These algorithms attempt to correlate the gray levels of pixels within a finite neighboring window. A central problem of the area-based algorithms is to find the optimal size of the window. While the window size must be large enough to include enough intensity variation for matching, it must be small enough to avoid the effects of projective distortion.
The second class is the feature- based algorithms. They extract features of interest from the image, such as edges, and match the features. The disadvantage of the feature-based algorithms is that they usually yield sparse disparity maps.

The third class global algorithms such as dynamic programming, graph cuts and belief propagation use global constrains over the entire image. Global algorithms can deal with the texture fewer regions and occluded regions well they performed over the whole images. In spite of having advantages of global algorithm, there have been few real time stereo matching implementations due to their high complexity. Among global algorithm, dynamic programming can be used to implement real time systems but is not robust since it doesn't consider vertical consistency

The stereo matching problems can formulate in terms of Markov Random Field as minimum energy function, to find energy minimization function is NP-hard. This means a general solution to this problem will take an unthinkably long time to reach a solution.

Belief propagation algorithm is an approach which find the approximate solution for minimum energy functions used for stereo matching. Belief propagation algorithm considers both vertical and horizontal consistency is most robust method in the presence of texture less regions and occlusion .

However,Even Belief propagation is computationally complex and often it implementation in real time is not possible. Current research is directed towards optimizing the BP algorithms and associated hardware for fast implementation.

Organization of report consists of consists of chapter2 explains about Literature survey,Operational concepts and terms are explained in chapter3 and chapter4 gives details about research design

Chapter 2

Literature Survey

Some of the major contributions in the optimization of BP stereo matching are as follows: Chia-Kai et.al[1] used Tile based belief Propagation scheme which reduces memory and bandwidth and used another technique fast message construction which reduces the complexity of message construction from quadratic to linear.so it can easily parallelized. Termination Criteria for Tile based BP are dependent on application and data so it can be possible to apply for some applications like stereo matching

Pedro F.Felzenszwalb and Daniel P.Huttenlocher [2] methods used are first distance transform technique to find new message by using cost function ,other method used are grid graph technique to update the messages. The third technique used are multi scale algorithm to perform BP in a coarse to fine manner.These techniques are used for solving early vision problems such as stereo ,optical flow and image restoration

Li Zhou et. [3] present a general comparison survey about software and hardware processing algorithms based on algorithm inherent characteristic, implementations, and architectures

optimization potential of an Belief Propagation algorithm measured in terms of of speed, parallelism, data bandwidth, memory storage, etc. implemented either for software or for hardware GPU, FPGA and ASIC designs are implemented in real-time embedded stereo vision application systems because of their high parallel processing capabilities and specific powerful calculation supporting components. Implementing GPU has more programming flexible and powerful computational capability than FPGA and ASIC but FPGA and ASIC have high performance, lower power consumption and cost Stereo matching system could be enhanced along with software and hardware technology development.

Young-kyu Choi et [4] used novel memory efficient algorithm for BP in which data size and transfer bandwidth is reduced significantly by storing only part of the whole image. In order to maintain the accuracy, the local messages are reconstructed by Graphic Processing Units (GPU) which is having advantage of available of shared memory.

Chi-Hua Lai e.tc [5] used method of parallelization of a belief propagation algorithm on the multicore processors to optimize the BP to implement on Graphic Processing Units (GPU).One of the most advanced paradigms is to apply this technique in inferring the 3-D position of an object for stereo matching .

Eduardo.M et.all [6] developed a FPGA implementation for depth map estimation using Belief Propagation algorithm for CAFADIS. CAFADIS IS A 3D video camera patented by the university of Laguna that performs depth reconstruction in real time. The main contribution of this work is the use of FPGA technology for processing the huge amount of data

Yu-Cheng Tseng et.a[7] worked on a method which is used for stereo matching is that by partitioning an image into block and optimize with Belief Propagation. This method reduces the memory storage size with good performance.

Radu Timofte et.al[8] studied Four-Color Theorem on Max-product Belief propagation technique. It is used in early computer vision for solving MRF problems where energy is to be minimized

Nama et.al [9] method used is task parallelism for Belief Propagation in acyclic graphs .The approach for task parallelism consists of constructing a task dependency graph for the input factor graph and then using a task scheduler to allocate tasks to the cores for parallel l execution,

Chapter 3

Operational Terms and Concepts

Stereo matching means The images are taken at slightly different view similar to our eyes ie. parallax effect that the object closer to us will appear to move quicker than those further away. The concept applies to stereo matching expect that the pixels on the near image to have a larger disparity than those in far away.
The MRF and BP are used to solve the Stereo matching problem

3.1 MRF model

The advantage of MRF model is that to recover the disparity map by not only looking at each individual pixel but also considering the neighbouring information to find best match There are four steps in stereo algorithm

1. Match cost computation
2. Cost Aggregation
3. Disparity Optimization
4. Disparity refinement

1. **Step1:Match cost computation**

   The cost is for every disparity value ,the cost function is intensity differences between two pixels. In probability term , the disparity value of each pixel is random variable it takes N discrete values. The cost function is defined as $\Phi(x_p, y_p)$

2. **Step2:Cost Aggregation**

   A MRF approaches uses second compatibility function which expresses compatibility between neighboring variables. This is known as pair wise random field The compatibility function is $\Psi(x_i, y_j)$ The joint probability of these two functions are:

   $$P(x_1, x_2, .x_N, y_1, y_2, ..y_N) = \prod_{ij} \Psi(x_i, y_j) \prod_{p} \Phi(x_p, y_p) \tag{3.1}$$

   Where N is number of nodes (i ,j) pair of neighboring nodes

3. **Step3:Disparity Optimization**

   Maximum A Posteriori (MAP) estimator is used to optimize the disparity for stereo images. The Maximum A Posteriori (MAP) estimator is used to find labeling of x_1, x_2, x_3
   By maximizing the probability ,ie. by taking the log of above equation (1)
   To maximize the probability which is minimizing above function in the form of

   $$P(x_1, x_2, .x_N, y_1, y_2, ..y_N) = \sum_{i,j} -\log \Psi(x_i, y_j) + \sum_{p} -\log \Phi(x_p, y_p) \tag{3.2}$$

   It can be expressed as

   $$P(x_1, x_2, .x_N, y_1, y_2, ..y_N) = \sum_{i,j} V(x_i x_j) + \sum_{p} D(x_p, y_p)) \tag{3.3}$$

   These functions are energy functions. The function used for datacost is the sum of absolute difference between label value x_p to data value y_p

4. **Step4:Disparity refinement**

   The loopy Belief propagation algorithm is used to find the solution for data and smoothness cost functions.
   The Belief propagation algorithm classified as sum-product algorithm or max-product algorithm.
   The sum-product algorithm finds the marginal distributions of node while max-product algorithm finds MAP estimate of whole image.
   For stereo algorithm mostly max-product algorithm is used. The max-product algorithm find best label as whole MRF.
   To use belief cost functions are converted into exponential functions

Chapter 4

Research Design

The analysis of BP algorithm for stereo matching is planned in two stages The research in Analysis of BP algorithm in stereo matching is planned in two stages.

1. stage1: MRF formulation on stereo image
2. Stage2: Applying BP to minimize energy functions The advantage of using Markov random field is that recovering the disparity map not only considering each individual pixel but also by considering neighboring pixel to find best match.

4.1 MRF formulation on stereo image:

MRF are undirected graphical model consist of nodes and links which encodes the spatial dependencies. MRF is modelled on 3×3 stereo image. The diagram below shows about MRF on 3×3 image.
The blue nodes are observed variables which represents pixel intensity values where as pink nodes are hidden variables which represents disparity values are trying to find. The hidden values are referred as labels. The link between these node represents a dependency which is known as markov assumption.
A markov assumption is that a node's state depends only on its immediate neighbours .This assumption is used to solve for the hidden variables in a efficient manner. The stereo problem can formulate in terms of MRF as energy functions. The energy functions basically sum up all the cost at each link for a given image and label. The aim is to find label that produces lowest energy. The energy functions contains two functions, datacost function and smoothnesscost function.
The datacost function finds the cost of assigning label value ie. Disparity value to data ie. pixel intensity values. The function used for this is absolute difference function.
The smoothness function enforces smooth labeling across adjacent hidden nodes. The commonly used smoothnessfunctions are shown below. The potts model is a binary penalising function with a single tunable variable. This value controls the smoothness of label.

Figure 4.1: Research design

Figure 4.2: MRF on 3x3 Image [?]

4.2 Applying BP to minimize energy functions:

BP algorithm is one of the algorithm used to find an approximate solution for an MRF. BP is message passing algorithm , A node passes a message to an adjacent node only when it is received all incoming messages, excluding the message from the destination node itself. Below diagram shows message passed from x_1 tox_2

Figure 4.3: Message Passage in BP [?]

To implement Belief Propagation two decisions should be made

Figure 4.4: Message schedule in BP

1. First one is max-product algorithm is used which finds the MAP estimate of the whole MRF

2. The second choice is message update schedule determines when message send to the node will be used by that node to compute messages for the node's neighbors.

An message schedule is to propagate messages in one direction and update each node immediately. For instance first node is in a row ,i would send message to the node at its right,i+1.Node i+1 would then use this message immediately along with the previously received from above and below to compute the message to the node i+2.
Once this has been completed for every row,the same procedure occurs in the up,down and left directions. This schedule would only require one iterations for this information to propagated.
This feature of the "$up - down - right - left$" message passing schedule causes the belief propagation algorithm to converge very quickly.
The diagram below describes about Message schedule in BP .

MATLAB is used to simulate functions in the proposed research work.

Chapter 5

Conclusion

1. The literature survey on major contributions in optimization of stereo matching technique using Belief Propagations are studied.
2. The operational concepts and terms related to Markov Random Field and Belief propagation are studied.
3. The implementation of stereo matching using BP are studied and understands the issues in implementation.

Bibliography

[1] Chia-Kai Liang,Chao-Chung Cheng,Yen-Cheieh Lai, “A Hardware-Efficient Belief Propagation”, *IEEE Transactions On Circuits And Systems For Video Technology* , Vol;21,No.5,May,pp, 2011.

[2] Pedro F. Felzenszwalb,Daniel P.Huttenlocher, “A Efficient Belief Propagation For Early Vision”, *International Journal Of Computer Science* , Vol. 41-54, No.2, February, pp, 2006.

[3] Li Zhou, Tao Sun, Yuanzhi Zhan and Jia Wang, “Software and Hardware Implementations of Stereo Matching, ”, *International Journal of Electronics and Informatics*, Vol.7, No.4 (2014), pp.37-562, No.1, 2014.

[4] Young-KYU Choi,Williem and In Kyi Park “Memory Efficient BP in stereo matching on GPU ”

[5] Chi-Hua Lai,Kun-Yuan Hsien,Shan-Honlai and Jeng Kuen Lee, “ Parallelization on Embedded Multicore Processors for Stereo Vision .

[6] Edurdo Magdaleno,Jonas Philipp Luke,Manuel Rodriguez and Jsei Manuel Rodriguez, Keita Yasutomi, “Design of BP based on FPGA for the multistereo CAFADIS camera”, *Open Acess Sensors*, ISSN 1424-8220

[7] Yu-Chang Andnelson Chang, “Low Memory Cost Block-Based Belief Propagation For Stereo Correspondence”, *IEEE Transisition*, 1-4244-1017-7187

[8] Radu Timofte,Lucvan Gool,“Efficient Loopy Belief Propagation Using The Four Color Theorem”,*Isics,Esat-Psi/Iminds V,Belgium,Computer Vision Lab,Zurich,Switzerland Computer Vision Lab* , .

[9] Nam Ma,Yinglong Xia,Viktorprasanna, “Task Parallel Implementation Of Belief Propagation In Factor Graphs”, *This Research Was Suppored By U.S.National Foundation Under Grant No.Cns-101880.*

[10] http://nghiaho.com/notes/Markov Random Field,Loopy Belief Propagation,stereovision.

[11] Tappen,M.F. and Freeman,W.T., “ Comparision of graph cuts with BP for stereo,using identical MRF parameters ”, *In IEEE International conference on computer vision*,2003.

[12] Jianguo Ding,“ Probabilistic Inferences In Bayesian Networks”, *International Journal Of Computer Science, Arxiv:1011.0935V2,*, 5 November 2010.

[13] Frank R.Kschischang,Brendan J.Frey,Hans Andrea Loeliger, " Factor Graph and The Sum Product Algorithm", *IEEE Transcations On Information Theory* ,Vol 47. No.2, Feb,2001.

[14] Erik.B.Sudderth And William T.Freeman , "Signal And Image Processing With Belief Propagation ", *Accepted To Appear In IEEE Signal Processing Magazine*,

[15] Dan Yuan, "Understanding Belief Propagation And Its Applicatons", *Department Of Computer Engineering,University Of California.*

[16] Hans Andrea Loeliger, "An Introduction To Factor Graphs", *IEEE Signal Processing Magazine* , 2004

[17] W Freeman,E.C.,Pasztor and O.T.Carmichal, " Learning Low level Vision ", *In International journel of computer vision*,40(1);25-47,2000

[18] Tappen,M.F. and Freeman,W.T., " Comparision of graph cuts with BP for stereo,using identical MRF parameters ", *In IEEE International conference on computer vision*,2003.

[19] Judea Pearl, "Probabilistic Reasoning in Intelligent Systems ", *Kaufmann Morgann Publishers*,Second Revised And updated Edition,San Francisco, California, 1998.

[20] Marl L Lrieg," Tutorial on Bayesian Belief Networks ", *Electronics and Surveillance Research Laboratory*,Australia,December ,2001.

[21] http://www.wikipedia.com